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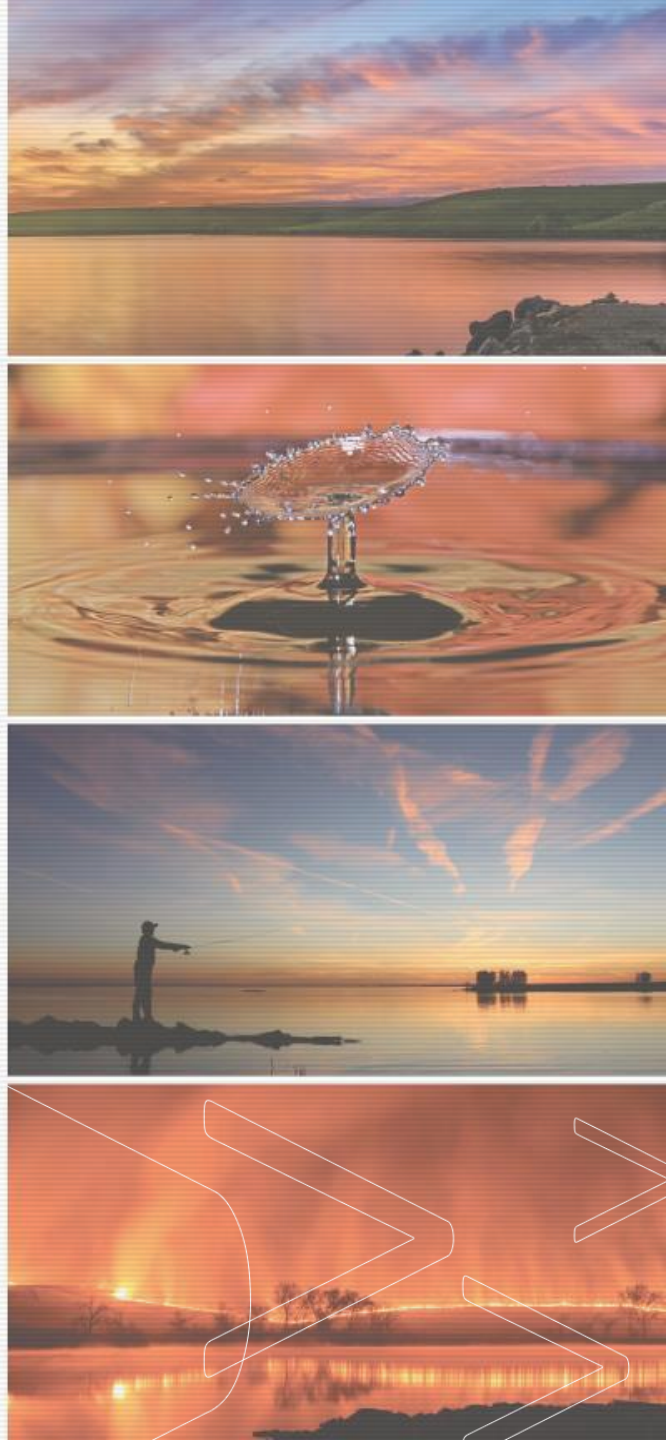
Modeling Nutrient Removal in Constructed Wetlands Collecting Terraced Field Runoff

Governor's Conference on the Future of Water in Kansas

2019

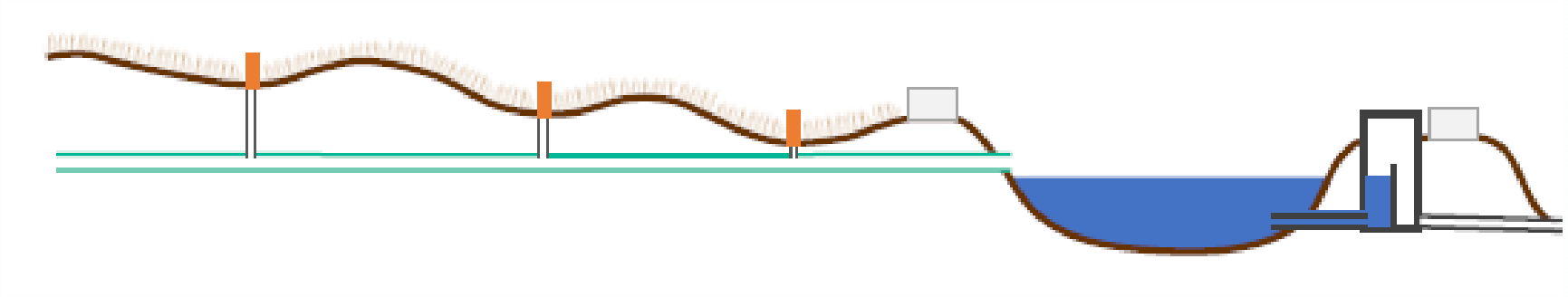


Project Scope

This project examines the water quality impacts of three wetlands constructed to provide on-site collection of storm runoff from tiled outlet terrace (TOT) drainage systems

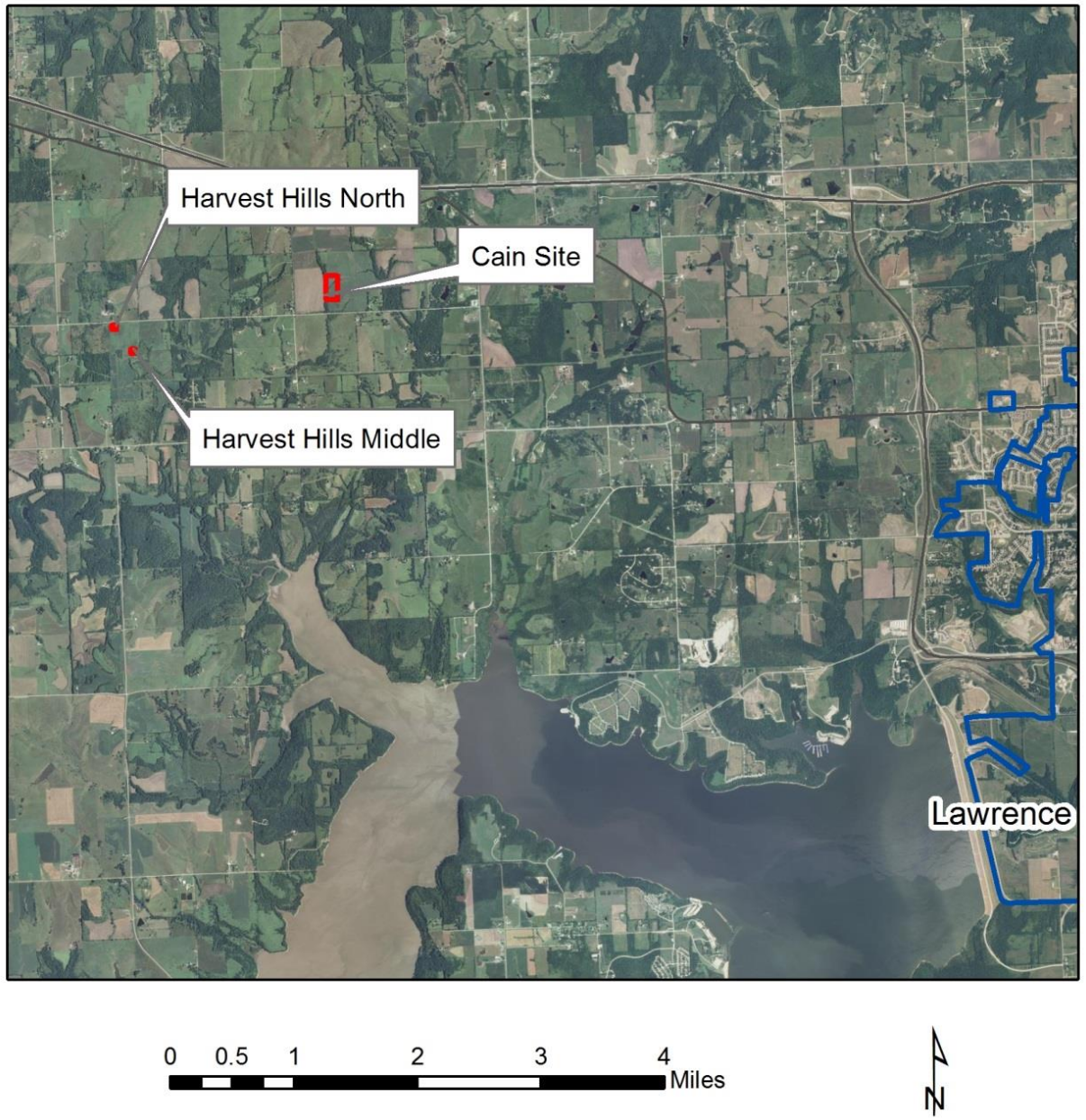
Tile Outlet Terrace Drainage Systems

- Underground tile drains allow for:
  - > More planting area
  - > Faster drainage
- Without treatment, TOT drains can increase nutrient and TSS transport to receiving waters

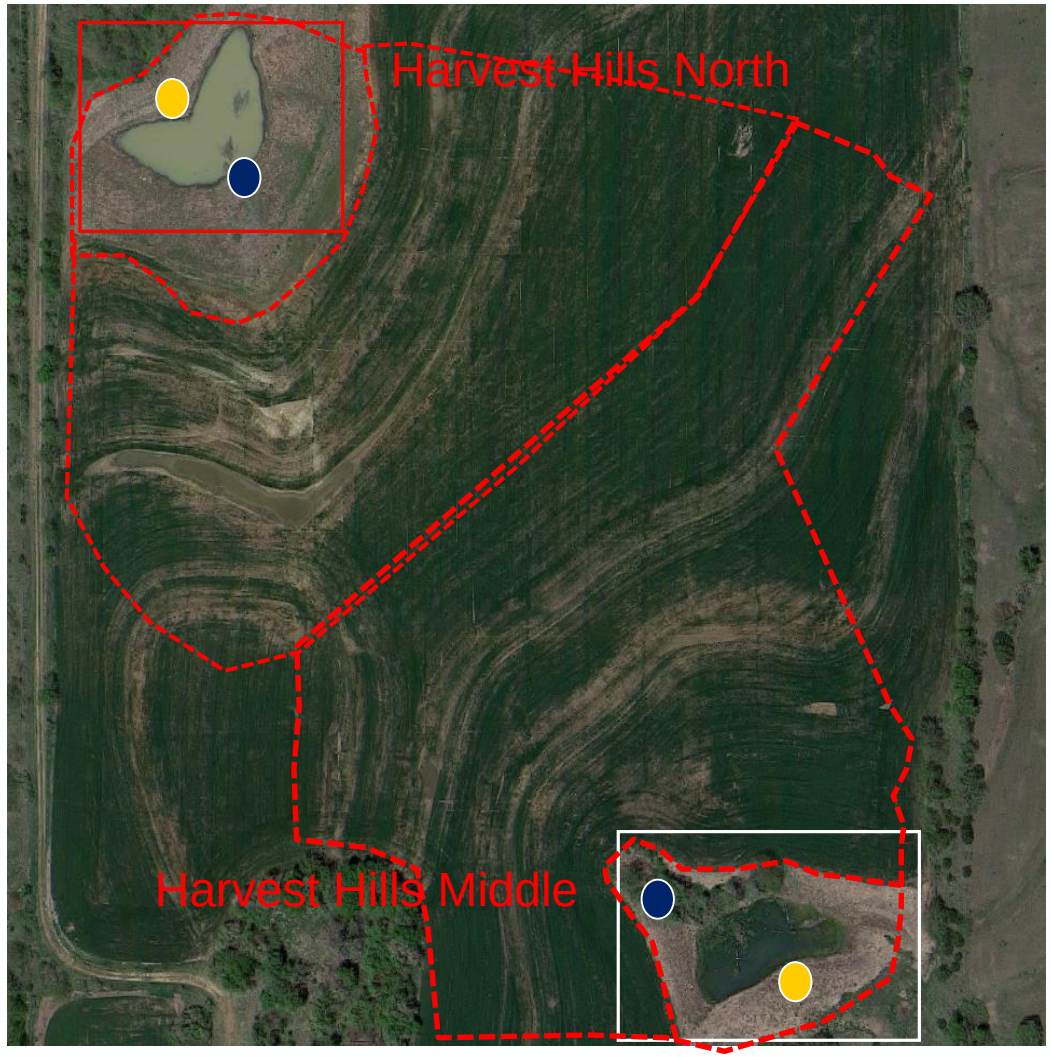


Three treatment wetlands were constructed in the Upper Wakarusa watershed in Douglas County, Kansas between 2008 and 2011

All drain to Clinton Lake, which supplies drinking water to the City of Lawrence



Harvest Hills Sites



Inlet pipe Outlet weir

- Two field portions, each with three planted terraces
- Similar drainage areas (10-11 acres), planting patterns, and management activities
- Wetland volumes:

  HHN: 0.91 ac-ft

  HHM: 1.73 ac-ft
- Runoff collected at tile drainage outlet to pond, and in pond effluent weir box
- North site has exposed riser on 2nd terrace, leading to increased sediment transport

Mass-Based Removal, 2015

	TN		TDN		TP		TSS	
	%	kg/ha	%	kg/ha	%	kg/ha	%	tonne/ha
HH-N	26%	102	21%	47	34	22	65%	38
HH-M	16%	46.5	15%	33	39	14	57%	9.6

Dissolved P averaged < 0.3 mg/L in influent runoff at both sites

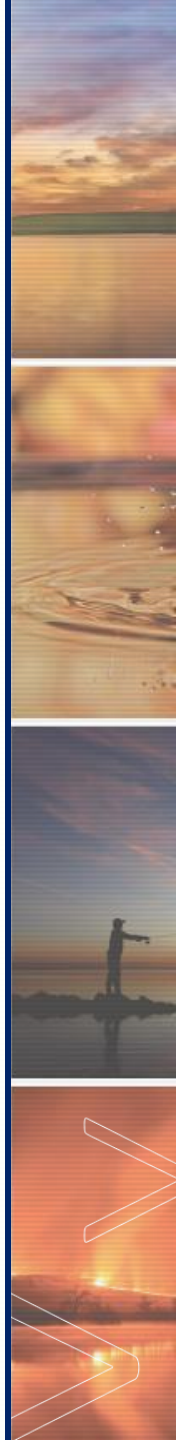
Despite similar wetland construction and vegetation, notable differences in nitrogen removal

Modeling Goals

1. Develop models for the study sites to better understand nutrient and TSS removal patterns

2. Predict wetland performance across a wider range of rainfall and weather patterns

3. Use results to estimate impact at other locations



Modeling Process Flow

Upland

- Runoff Depth
- Runoff Hydrographs

Wetland Hydrology

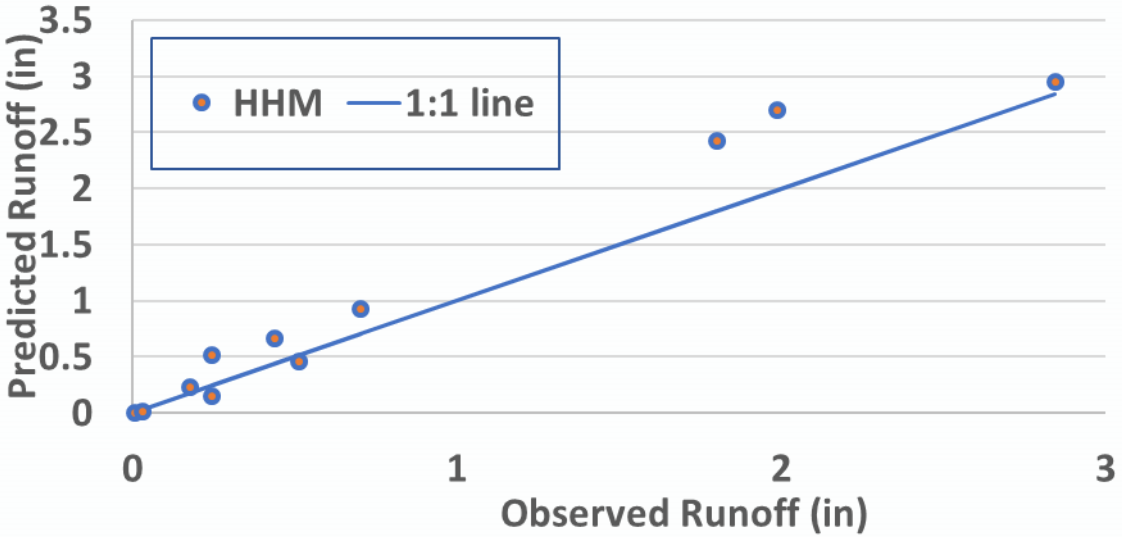
- Water Level
- Retention Time

Wetland Chemistry

- Nutrient Removal

Terraced Field Runoff Model

- Uses HEC-HMS to determine runoff through curve number approach
- Each terrace modeled as a linked sub-basin + reservoirs
- For these small, cropped watersheds, runoff depends on
  - Antecedent precipitation
  - Vegetative cover
- Seasonal pattern for ARVI, with greatest cover in July-September



$$CN = a.API^2 + b.API + c.ARVI + d$$

Antecedent Precipitation Index

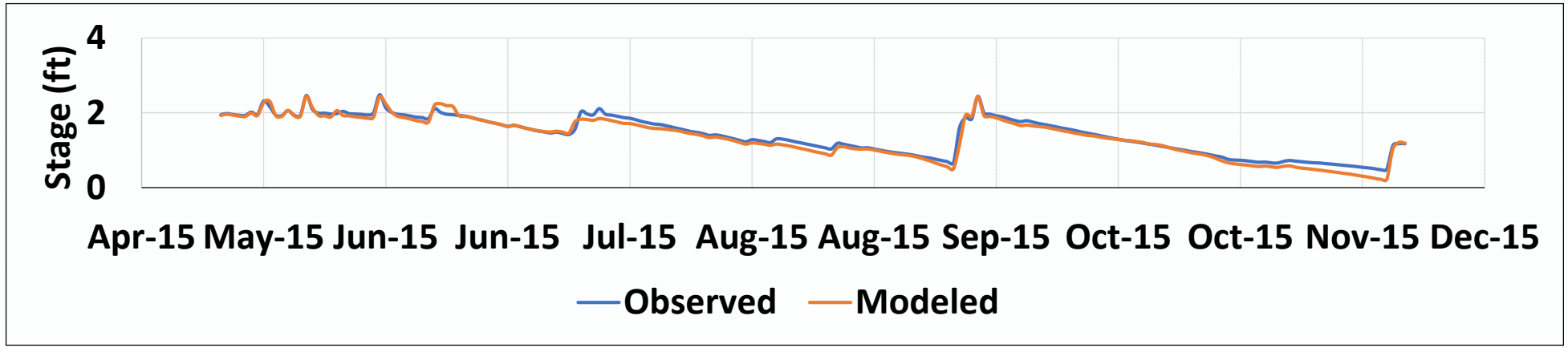
$$API_d = k.API_{d-1} + P_d$$

Atmospherically Resistant Vegetation Index

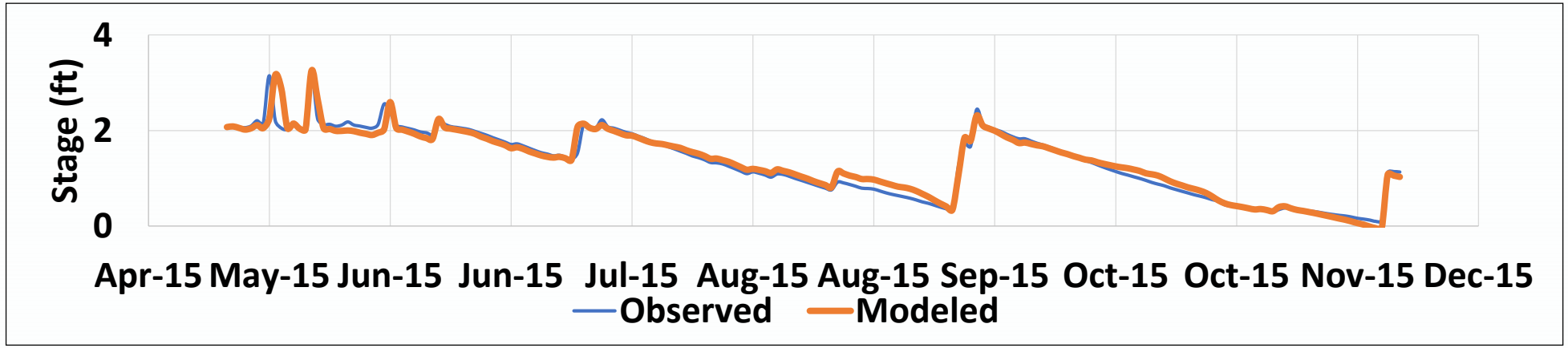
$$ARVI = \frac{NIR - RB}{NIR + RB}$$ (Landsat 8 bands)

Wetland Water Budgets

HHN



HHM

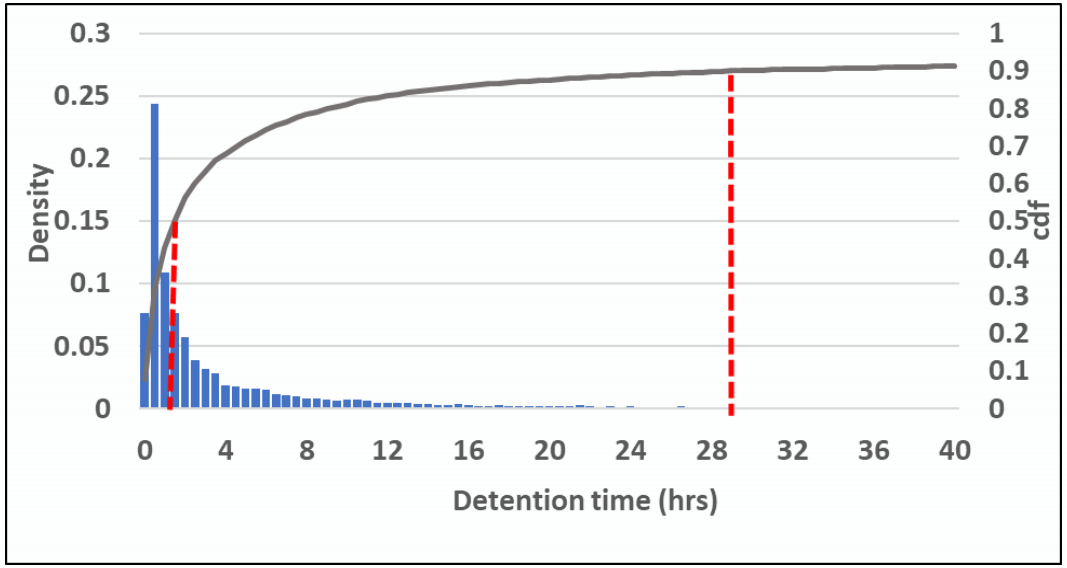


Detention-time Distributions for Individual Storm Events

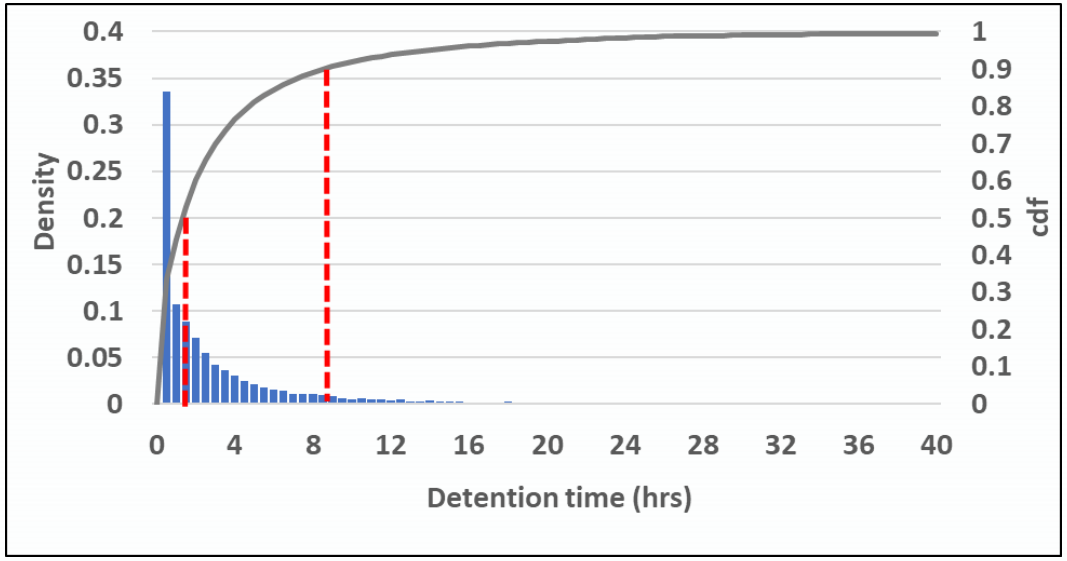
Monte-Carlo simulation varying main runoff and wetland variables based on reported ranges

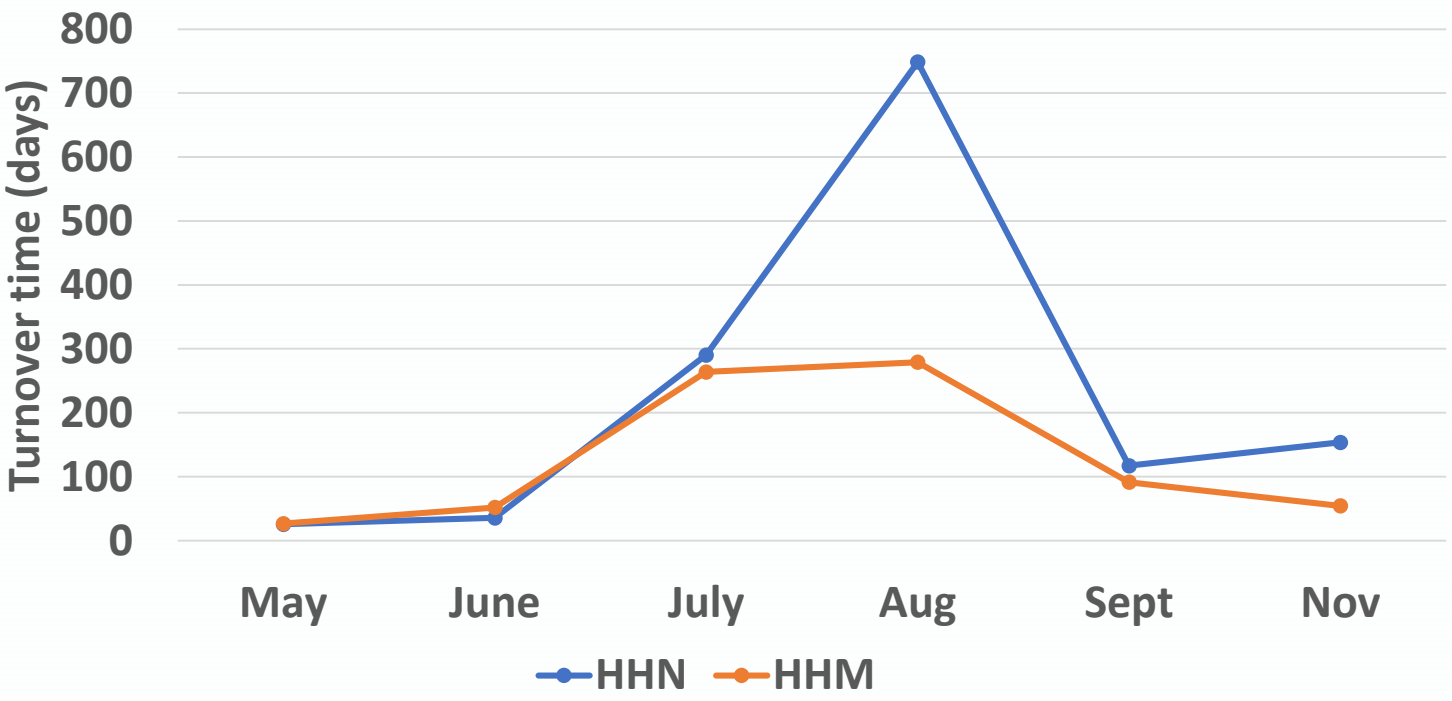
HHM site has lower detention times at both 50% and 90% of the CDF

HHN



HHM





Turnover rate shows strong seasonal effects

May-June values comparable to freshwater marshes

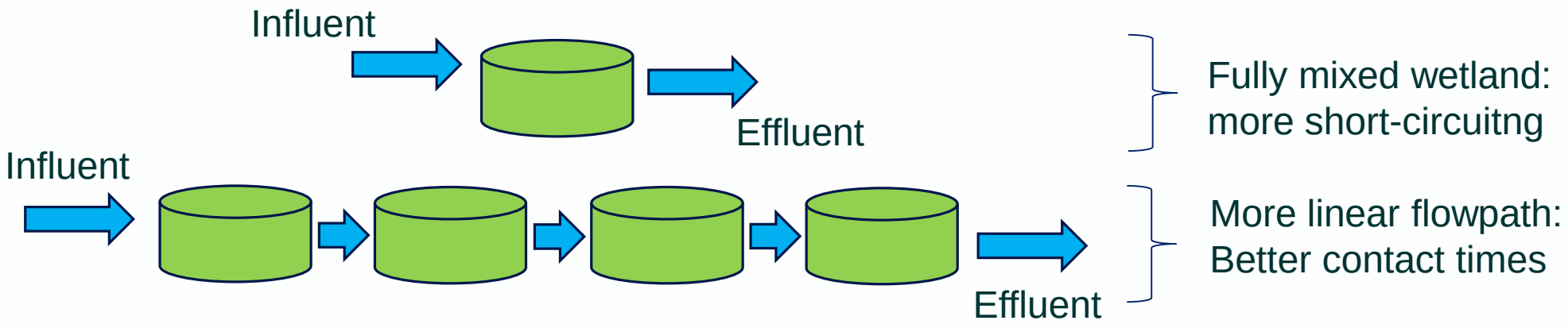
July- Sept. more typical of closed systems such as peat bogs

Modeling Nutrient Removal

- Modeling must consider both
  > The rates of pollutant removal through chemical reaction
  > The hydrodynamics of flow through the wetland

- Stored volume changes during storm events

- Relaxed Tank in Series model has been used to successfully model nutrient removal in stormwater wetlands
  - # of tanks gives indication of mixing in the wetland



Modeling Nutrient Removal

Relaxed Tank In Series Model :

$$\frac{(C_{out} - C^*)}{(C_{in} - C^*)} = \left(1 + \frac{kt}{Ph}\right)^{-P}$$

C_{out} = effluent concentration (mg/L)
C_{in} = influent concentration (mg/L)
C* = background concentration (mg/L),
k = modified reaction rate constant (m/yr.)

t = detention time (days)
h = wetland free water depth
P = apparent number of tanks.

Background concentration (C*) is the lowest consistently achievable level of a given compound in the wetland

Nutrient Removal Model

$$\frac{(C_{out} - C^*)}{(C_{in} - C^*)} = \left(1 + \frac{kt}{Ph}\right)^{-P}$$

Objective

Calibrate → k, P
Reaction rate Constant (k)
Number of CSTRs (P)

Tasks

"Cout" / "Cin"
(Wetland Field Sampling)

"h"
(Water level Depth)

"t" = edA/Q
(Detention Time)

Water Budget Model

Wetland Outflow Model
(Qout)

Upland Runoff Model
(Qin)

Wetland Dimensions
(Vol. Efficiency → e)
(Depth of the Pond) → d
(Surface Area) → A

Estimating Background Concentrations

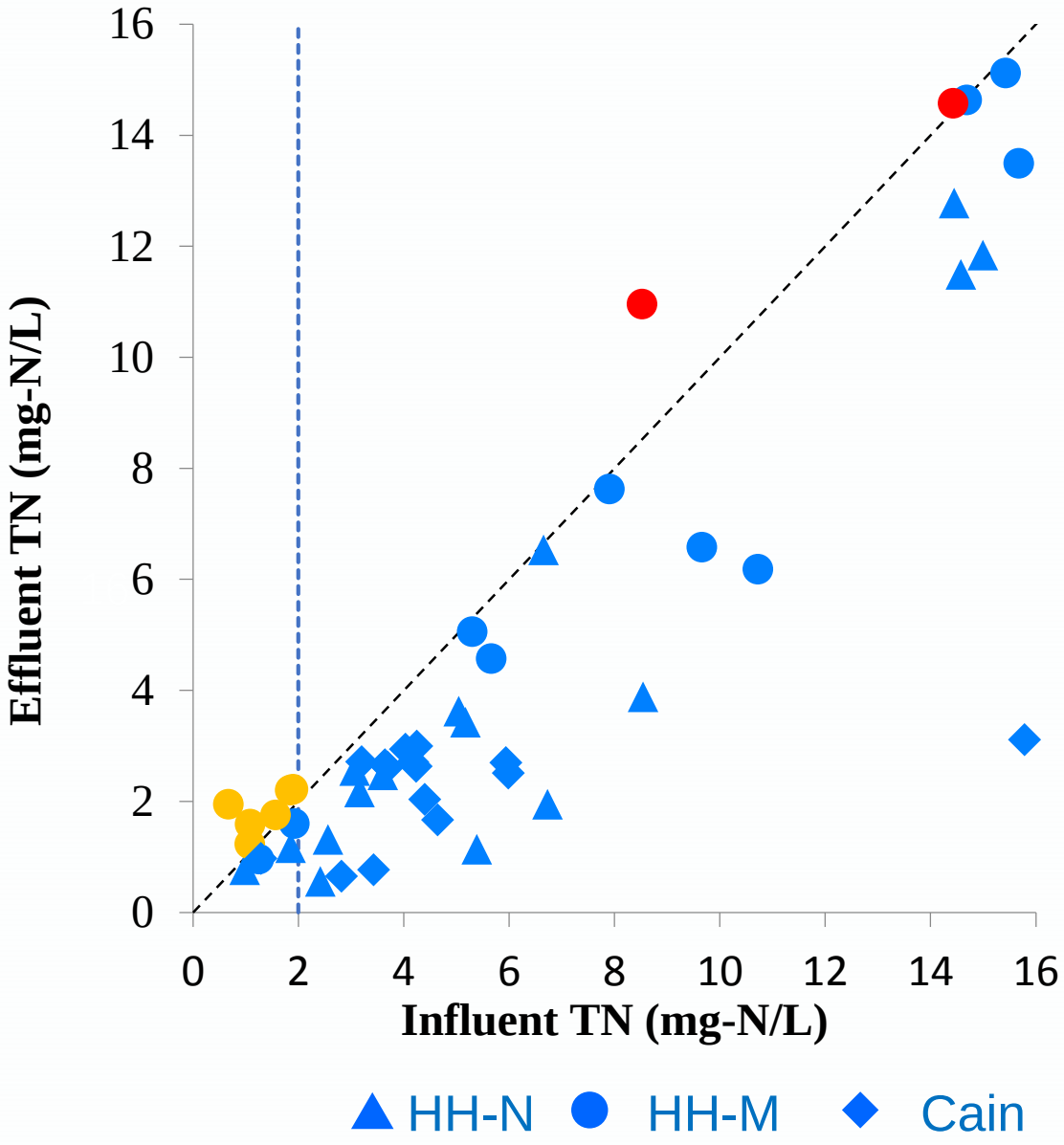
Field sampling results used to estimate 'background' concentrations for individual constituents

Graph at right shows TN concentrations in 2014-15.

Below 2 mg/l, little relationship between influent and effluent values

We used C* = 2 mg/l for TN, 1 mg/l for TDN and 10 mg/l for TSS

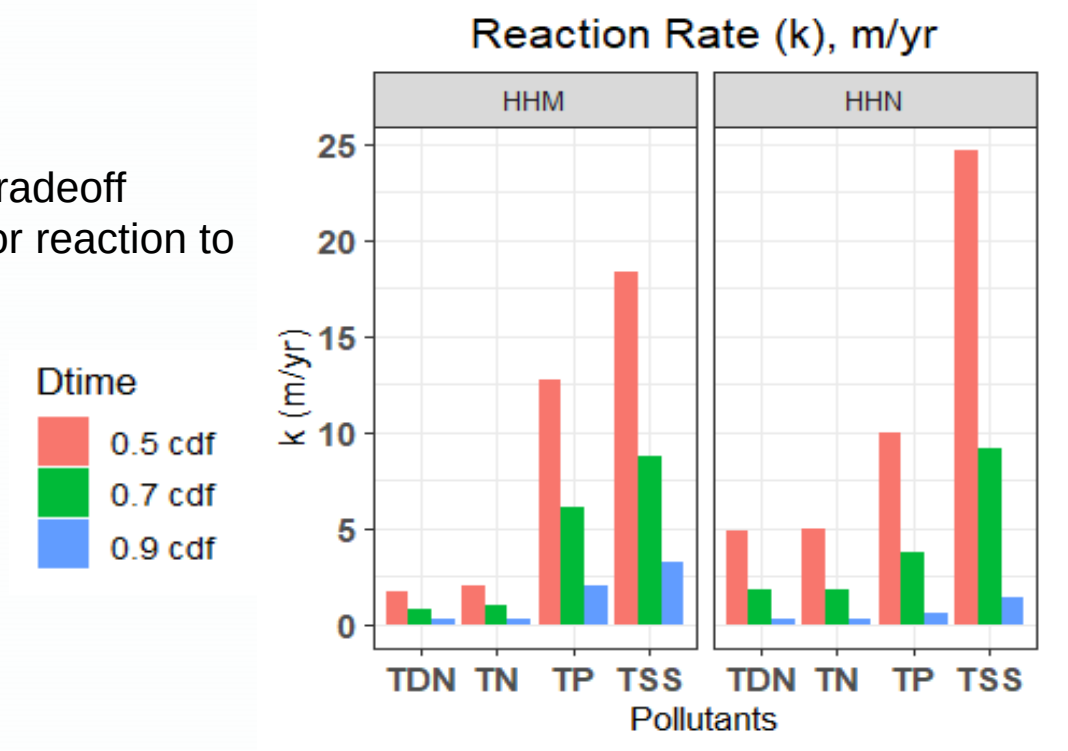
For TP C* ~= 0



Nutrient Modeling Results

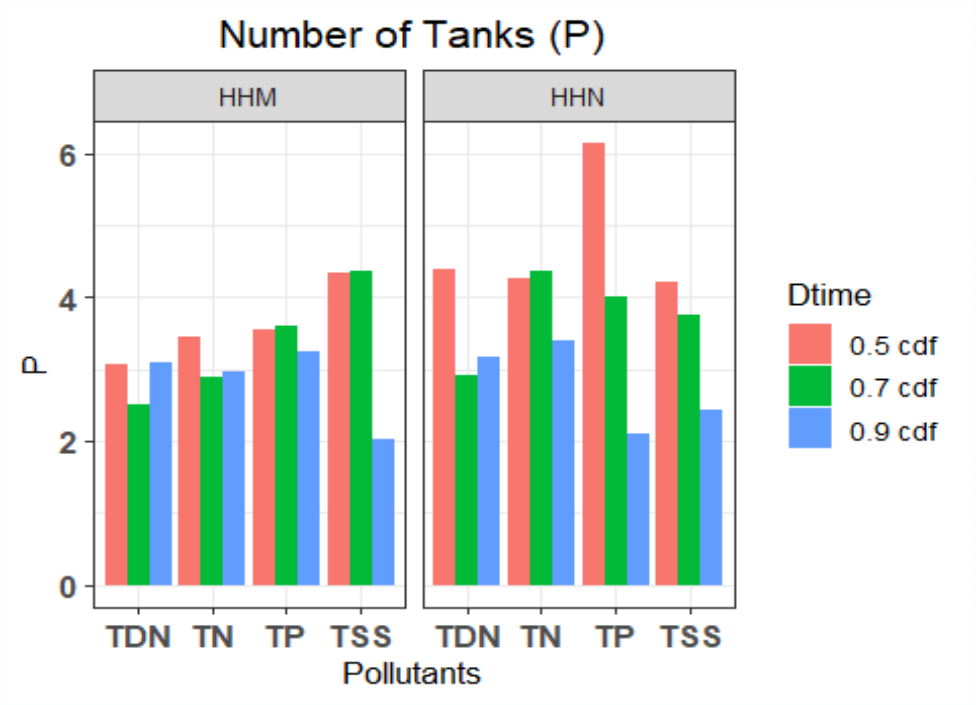
- Ranges of detention time distribution (i.e., 50, 70, 90% cdf) were obtained using Monte Carlo Analysis and used to account for variations in flow paths

- At given observed removal, there is a tradeoff between rate of reaction (k) and time for reaction to occur (t_d)

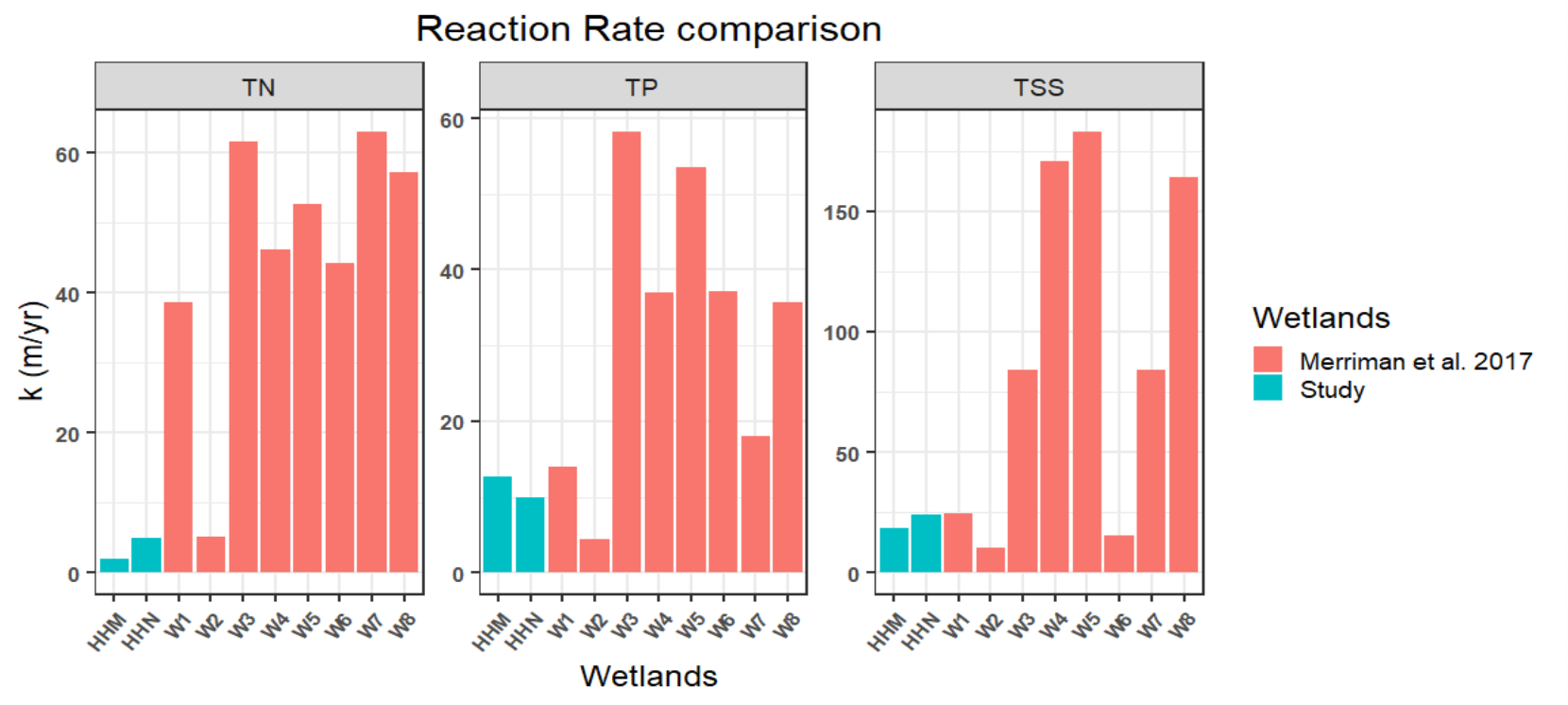


Nutrient Modeling Results

- Fitting results indicate more linear flow path (less short-circuiting) in the Harvest Hills North wetland at the same detention time
- TSS is less affected by flow patterns, as most solids removal occurs early in the wetland



Comparing Performance



- *k* values obtained here are on the lower end of reported values (Merriman et al. 2017)
- The lower *k* values are a combined effect of Sediment buildup, flow path channeling and seasonality effects.
  - ➢ Spring 2015 was an extraordinary precipitation pattern

Modeling helped quantify two different profiles for wetland performance

Full-flow conditions

- Occurs during wet months (April – June)
- Water level remains near maximum level
- Short detention times during storm events
- Less pollutant removal, especially N

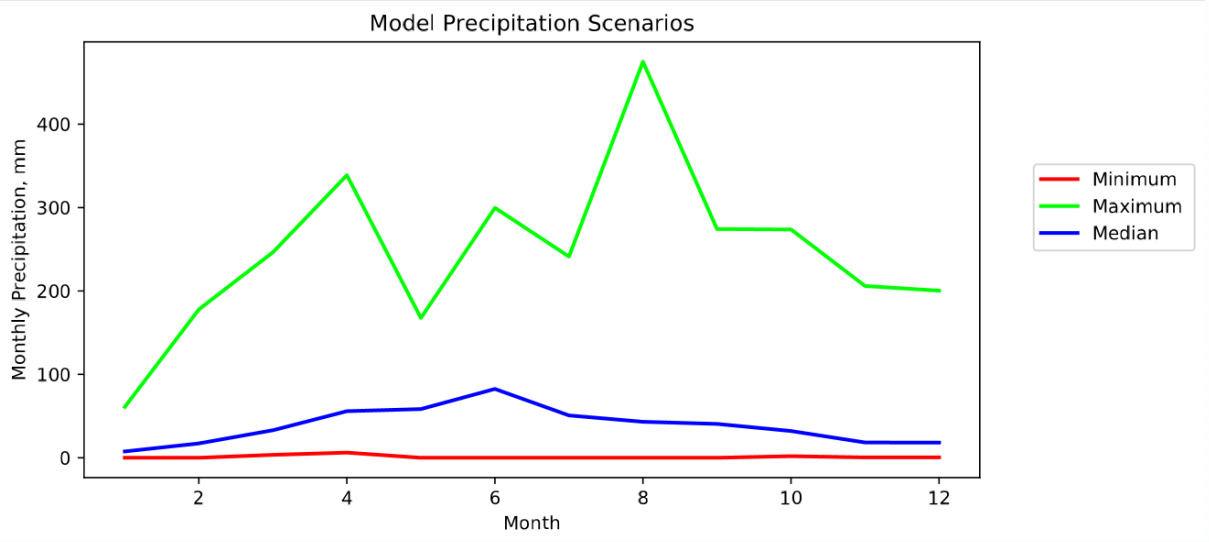
Isolated storm conditions

- Occurs from summer through fall
- Reduced runoff due to drier soil and more vegetation
- Water level drawdown between storm events
- Longer detention and more pollutant removal

Modeling helped assess existing wetland designs

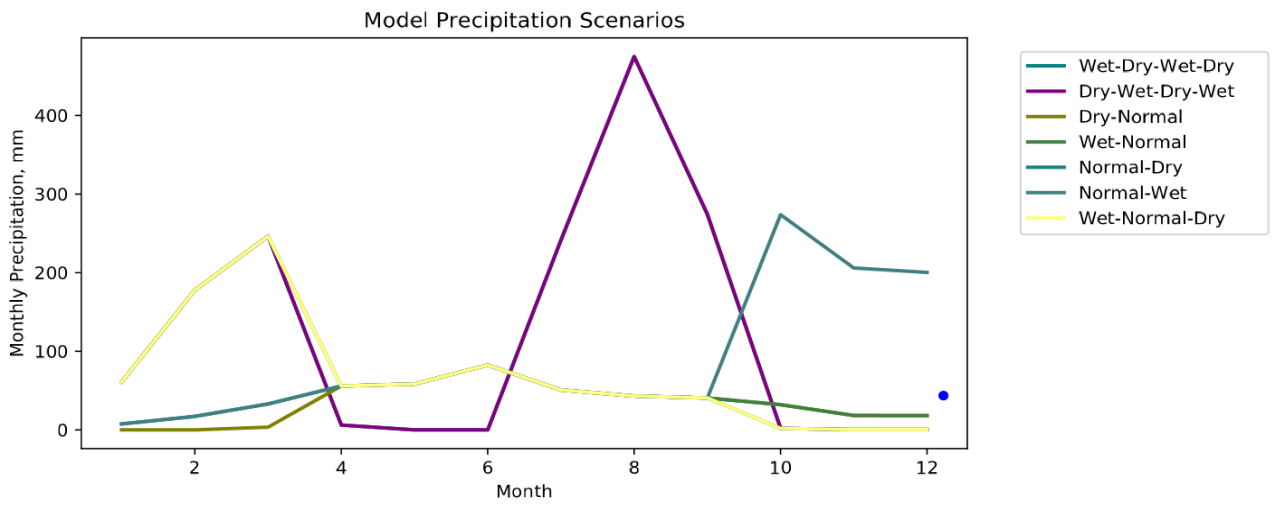
- HHN wetland had better (longer) flowpaths despite proximity of inlet and outlet locations
  - Result of early sediment deposition?
  - Preferential flow at HHM?
- Flow effects were greater for N than P
- Wetland performance could be improved by designing for longer contact times
- Limited impact during high-volume storm events or sequences

Models Provide a Tool for Predicting Wetland Impacts on Water Quality



Top: Baseline precipitation for wet, median and dry month conditions using USGS 15-minute precipitation data

Bottom: Scenarios compiled by combining months from the baseline cases



<u>Ongoing work</u>

1. Generalize some inputs (e.g. vegetative cover) to make models more portable

2. Examine impact of wetland design parameters on nutrient removal

3. Estimate wetland performance for different precipitation scenarios

Acknowledgements

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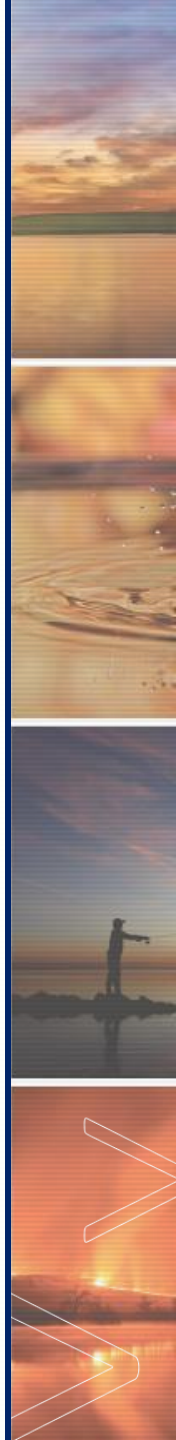
- Field sampling: Wes Stops (2016-18), Hyunjung Lee (2014-15) and Llynnann Luellen (2014-15)

- Additional assistance: Allison Dobie, Katie Wipfli

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